Data Fusion of Aerodynamic Database for Flight Simulation

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airinnova AB - profile

- Aerospace spin-off SME from KTH
  - Developing variable-fidelity MDO framework s & analysis tools for collaborative and integrated Aircraft Design
  - M. Zhang CEO
    - computational science & aeronautics : collaborative and integrated aircraft design using open-source tools
    - “middle player” role
    - equally conversant with industrial aircraft designers, software specialists, code developers and tool providers
  - offers advanced computational technology, e.g. CEASIOM framework for aircraft preliminary design

- airinnova’s strategic partnerships (universities, research institutes, companies)
  - Southampton, TU Munich, PoliMilano, Warsaw TU, MIT, Colorado U, DLR, ONERA, NLR, ...
  - SAAB, Airbus Bremen, Airbus D&S Manching, Embraer, Bombardier, Alenia, CFSE (Lausanne)
  - member Aerospace Cluster Sweden, user KTH-PDC , ...
  - member AIAA Aerodynamic Design Optimization Discussion Group (ADODG) - aero shape opt in constrained design

- Active in EU Projects – Aeronautics & HPC
  - Past – SimSAC, ALEF, NOVEMOR, AFLoNext
  - Current - “AGILE - Aircraft 3rd Generation MDO for Innovative Collaboration of Heterogeneous Teams of Experts”
    - led by DLR
  - partner EU-project PRACE (Partnership for Advanced Computing in Europe)
    - high-level optimization in aerodynamic design - carried out in SHAPE (SME HPC Adoption Programme in Europe).

- Typical work & services provided
  - Software: CEASIOM with semi-automated mesh.gen (RANS), SUMO, Edge, SU2
  - Create variable fidelity models with surrogate model techniques & data fusion
  - Construct aircraft S&C database and loads database with variable-fidelity modeling and data fusion
  - Surrogate-based optimization; data-driven and physics-based surrogate model development
  - E.g.: Aero-elastic design of flexible struss-braced wing aircraft, simultaneous aerodynamics shape and sizing optimization
1. Introduction & Background

- Aircraft 3rd Generation MDO for Innovative CoLLaboration of Heterogeneous Teams of Experts
- Aircraft multidisciplinary optimization using analysis framework
- From 2015 to 2018, part of Horizon 2020
- 19 partners (Industries, Research centers, Universities)
1. Introduction & Background

Preliminary aircraft design

- Requirements
- Concept Config (Init Aero, Mass info)
- Control Power Requirements
- Concept planform design and layout
- Aero optimisation
- Structure optimisation
- Propulsion Integration
- Config Freeze
- WTT
- $&C model

Looking at these steps:
- Absolute performance is not relevant
- Key is how our tools impact these steps
  - Timescale impact
  - Improve fidelity
  - Reduce re-work
  - Requirements validated earlier
DC-1 MDA Final setup
Context: DC-1 MDA

We are here!
3. DC1-MDA Aircraft Example

- Aircraft used for the AGILE Design Campaign 1 (DC1)
- Result of Design Campaign 0 (DC0)
- From semi-empirical methods
- Medium-range commercial airliner
- No experimental data available

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DC1-MDA</th>
<th>Unit</th>
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<tbody>
<tr>
<td>Wing span</td>
<td>28.1</td>
<td>m</td>
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<tr>
<td>MAC</td>
<td>3.73</td>
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</tr>
<tr>
<td>Wing area</td>
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<td>m²</td>
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<tr>
<td>MTOW</td>
<td>39’750</td>
<td>kg</td>
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Step 1 - CPACS file received
Required data

CPACS file must contain:

• Aerodynamic dataset (stability and control derivatives)
• Propulsion system data
• Mass breakdown data (mass, cg, Inertia)
• Geometric data
2. CEASIOM history and current status

- Data fusion for aero-database for S&C
- Under development within AGILE
  - Making CPACS compatible

1. Initialization
2. Sampling
3. Co-Kriging surrogate model
4. Sampling updates
5. Final surrogate model
2. CEASIOM history and current status

• Smart sampling: Correct overall predictions by suggesting hi-fi samples at recommendation locations
• (in progress) scripting for automatically setting up and executing variable fidelity analysis
• 4D independent variables at most (CPACS format)
Step 2 – Create PHALANX simulation model

**Performance, Handling Qualities, Loads Analysis Toolbox**
- Automatic generation of simulation model
- Equations of motion based on multibody dynamics (nonlinear flight dynamics model)
- Selective fidelity (range of sub models is available)
Selective fidelity (example)

• CPACS file contains **detailed engine decks** (thrust, fuel flow as function of Mach, altitude and throttle setting)

  ![Engine modelled using look-up tables in PHALANX](image)

• Only **basic engine data available** (location on aircraft, bypass ratio and maximum thrust)

  ![Engine modelled using analytical functions](image)

  \[
  \frac{T}{T_0} = A - \frac{0.377(1 + BPR)}{\sqrt{(1 + 0.82BPR)G_0}} ZM + (0.23 + 0.19\sqrt{BPR})XM^2
  \]
Step 3 – virtual flight test

• Trim and handling qualities analysis
  (for range of flight conditions)

Basic results
• Trim attitudes and control settings
• (including crosswind / engine out)
• Short period
• Phugoid
• Dutch roll
• Spiral
• Roll mode
• Push pull manoeuvre simulation
• Roll manoeuvre simulation
• Gibson criterion
• Maximum pitch acceleration (take-off)
• Response to turbulence and gusts
Step 4 – Piloted simulation
Movies

• Pitch maneuvers:
  • Angle of attack
  • Pitch rate
  • Pilot input (roll)

• Roll maneuvers:
  • Roll rate
  • Pilot input (roll)
  • Pilot input (pitch)

• Rollover:
  • Roll rate
  • Load factor
  • Pilot input (roll)
Questions ?
Challenge for Swedish Aerospace to remain competitive

DLR supports Airbus with computational tools

- Example: writing new modern code **FLUCS** to replace **Tau**: high order, large scale computing (exaflop)
- Integrated design, MDO aero-structures

CFD challenges in aerospace industry:

- Mihai’s presentation, Spalart paper, *Aero J*
- Algorithms and physical modeling
- Integrated with other disciplines for MDO
- Hybrid RANS-LES
- Improved user interfaces
- Example: **Off-design flow physics**

HPC challenges

- True exaflop performance
- See Mihai’s presentation ... **significant**!
New CFD code for aeronautical applications
- Developed from “scratch”
- Based on knowledge from Edge and other codes
- Finite volume (DG like)
- Allow for Higher Order
- HPC, highly scalable, high efficiency

Open source under appropriate license
- OpenFoam type
- Allow for proprietary developments / additions

Design & Optimization
- Linearized equations, Jacobians for adjoint and/or implicit treatment
- Surrogate-based optimization

Allow coupling & solving with structures – multi-physics
- Integrated aero-structures design
C3FD, some thoughts

- New CFD code for aeronautical applications
  - New code developed from “scratch”
  - Based on knowledge from Edge and other codes
  - Minimum inclusion of existing parts of codes

- Focus on unstructured grids for realistic large scale applications
  - Finite volume, Finite Element (DG like)
  - Finite difference in structured domains/blocks
  - Allow for Higher Order (FE, FD)
  - HPC, highly scalable, high efficiency

- Open source under appropriate license
  - OpenFoam type
  - Allow for own proprietary developments

- Multiphysics
  - Navier-Stokes
  - Allow for solving and coupling with structures, heat transfer …

- Design & optimization
  - Linearized equations, Jacobians for adjoint and/or implicit treatment
  - …
C3FD, continued

- **Work plan**
  - Prototype code produced within a year
  - Contents of prototype to be discussed, e.g. FV + DG + Fluid + Structure
  - To be reviewed & approved and further extended

- **Related similar projects**
  - Flux at DLR (FV, DG, adjoints …)
  - SU2 in US
  - OpenFoam

- **Programming details**
  - Minimize code volume (# lines)
  - Python, Fortran, C++ … ???
  - Classes, …